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sense and simplicity

A Manufacturer’s Perspective on System Reliability for SSL products

J. Gaines, W. van Driel (Responsible for SSL Reliability)
Philips Lighting
July 18th 2012

Topics

Where are we now with reliability?

What can we do better?

- Speed it up, with accelerated testing
- Make it more cost effective, by designing optimally
  - Avoid underdesign → premature failure
  - Avoid overdesign → cost higher than needed

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Reliability - Definition

Reliability - the probability that the equipment will perform its **intended function**, **under stated conditions**, for a **specified period of time** without failures

- What function should the equipment perform?
  (E.g.: give light, dim, change color, …)
- Under what application (use) conditions should the equipment function?
  (e.g.: temp., humidity, vibration, …)
- How long should the equipment last?
  (e.g.: Technical or economical lifetime)

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Lighting Transformation

Conventional

Operating lifetime is short

Product lifetime in the market is long

→

SSL

Operating lifetime is long

Product lifetime in the market is short

More testing/ product!

More products to test!

So, we have to do a lot of work to ensure long lifetime, for a product we are only going to sell for a short time.

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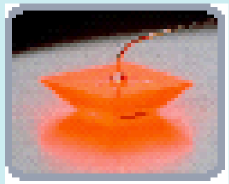
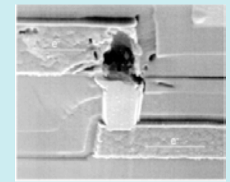
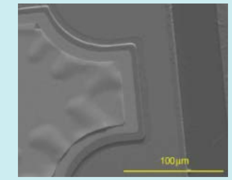
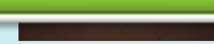
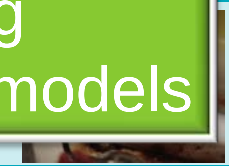
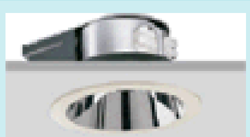
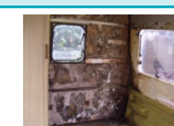
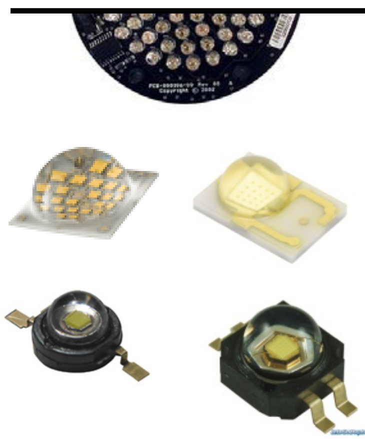
Identified Critical Failure Modes

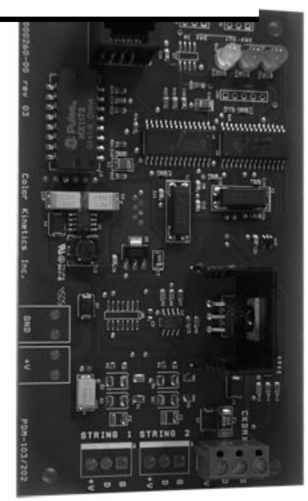
Level		Identified Failure Modes
0: Bare Die		•LED catastrophic failure •Lumen depreciation (several causes) •Degradation of active region / ohmic contact •Electro-migration causing dislocations •Diffusion of metal atoms to the active region •Current crowding (uneven current distribution) •Doping related failures  
1: Packaged LED		•Yellowing of packaging materials (degradation/aging) •Electrostatic discharge (ESD) •Interconnect failure (solder or die-attach)   
2: L... sub...		•Short (f.e. due to solder bridging)  
3: LED module		•Casing cracks •Driver failures •Optic degradation (browning, cracks, reflection change) •ESD failures 
4: Luminaire		• Fractures (f.e. due to vibrations) • Moisture related failures (f.e. popcorning) •Corrosion due to water ingression •Deposition of outgassing material on the optics 
5: Lighting system		•Software failures •Electrical compatibility issues • Installation & commissioning issues  

Each FM has a certain ppm level, which we need to understand, minimize or solve & understand using reliability lifetime tests and analytical / numerical models

SSL products have 5 key-components

1	LED engine
2	Optics
3	Electronics
4	Cooling system
5	Mechanical construction





Experience-Based Approaches: Derating

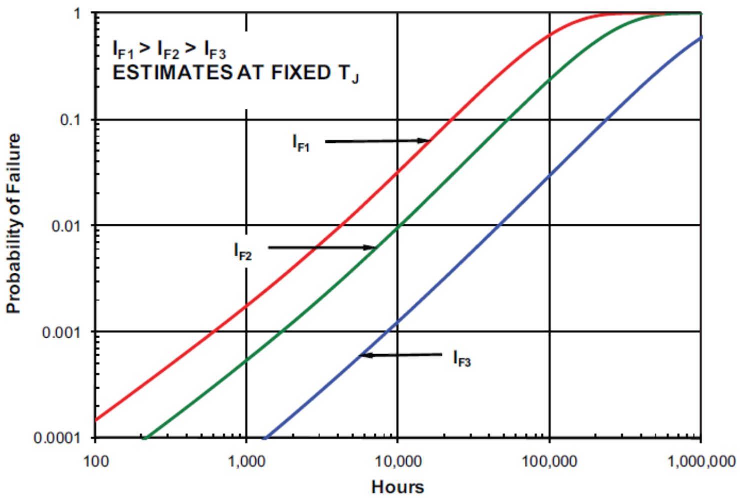
- Basic principle: Same as your mother and father told you as a child: Treat your toys gently and they will last longer.

- Component manufacturers generally specify maximum temperatures, currents, etc → but life will be reduced.

- How gently do you have to treat it?
    - Depends on how long you want it to last.

- Based on experience with a component, we can come up with derating curves.

- But what if a new component comes along or a change is made to an existing component? Mature change management is needed.



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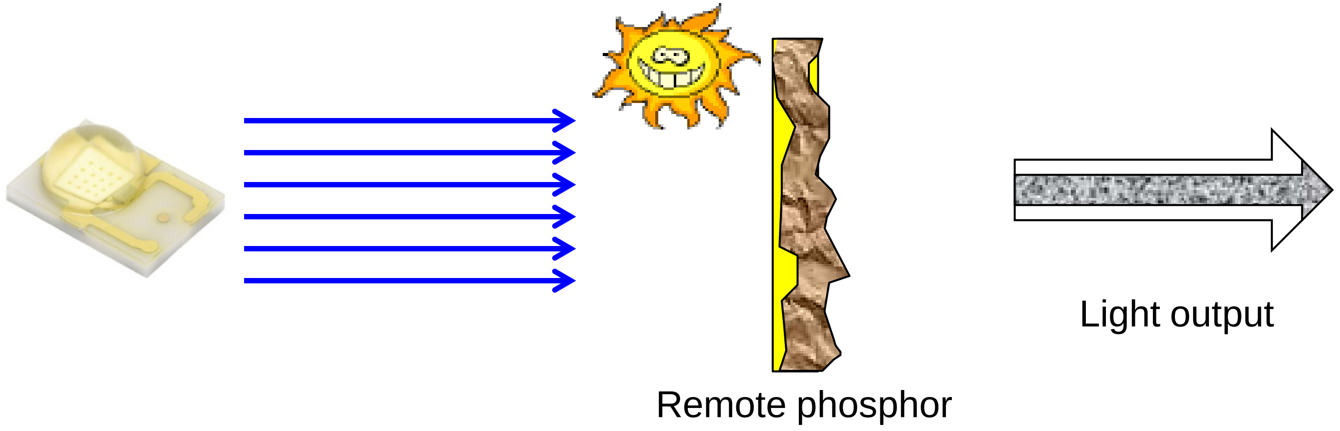
Experience-Based Approaches: Derating

- Treat component A gently via derating
- Treat component B gently via derating

- But somehow, there is a problem when A and B are integrated. Interactions between the components (not foreseen) may create new failure mechanisms.



- There may be 100-200 components in an LED lamp/luminaire. Plenty of potential for unexpected interactions and failures.

Experience-Based Approaches: Stress Testing

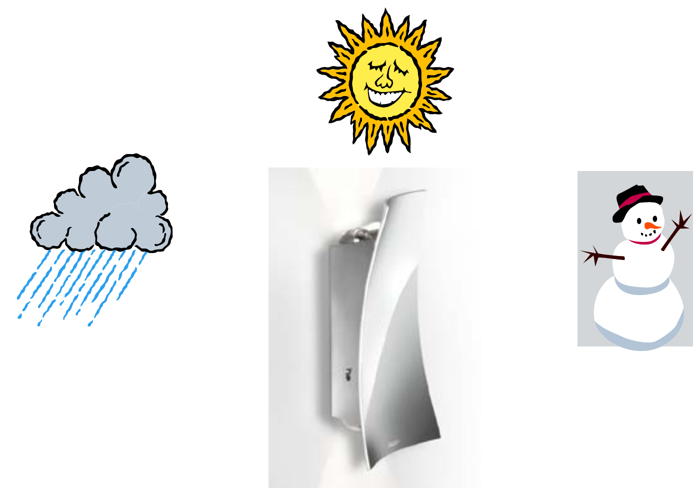
- During development, put products through a battery of tests, to see if they survive.
  - Extreme temperatures
  - High/low line voltage
  - Extreme humidity
  - Vibration
  - Different operating conditions (eg. On/off, vary CCT, dimming,…)
  - Chemical exposure (e.g. salt spray)
- But correlations between test results and product lifetime are experience-based “rules of thumb”.
- What if something changes?

System Reliability

- In principle: Component failure ≠ System failure
- Each component in a system exhibits its own failure behavior
- This component failure behavior needs to be captured by:
  - Experiments by using at least 3 accelerated testing conditions
  - Numerical / analytical models that describe the *Physics of Failure*
- Interactions between the components need to be captured by:
  - Testing sub-systems
  - Testing the total system
  - By accelerating environmental user conditions in a physically correct manner

Acceleration

Experiment to assess the endurance of devices by “accelerating” shipment, mounting & application conditions



Stress Test
(test conditions)

Environmental Test
(field application)

$$\text{Acceleration Factor} = \frac{\text{time to failure in application}}{\text{time to failure in test}}$$

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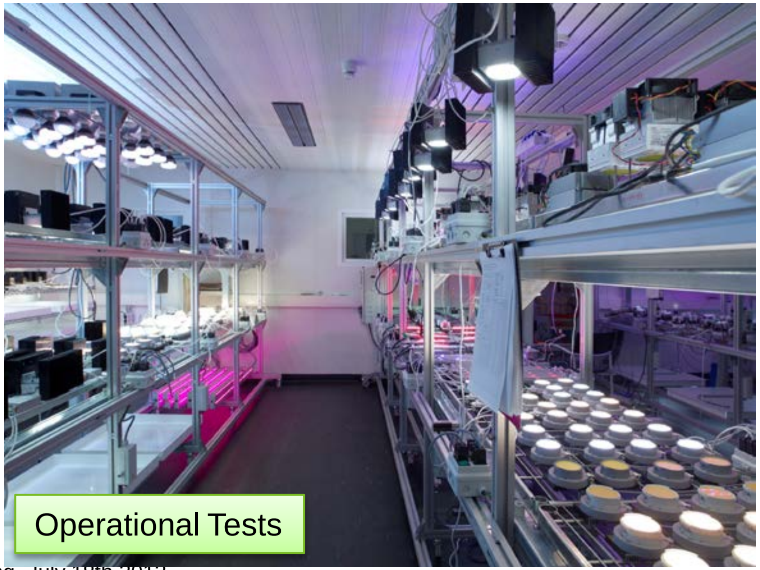
Examples


Humidity Damp Heat


Highly Accelerated Life Test


Sleeve tests


Operational Tests

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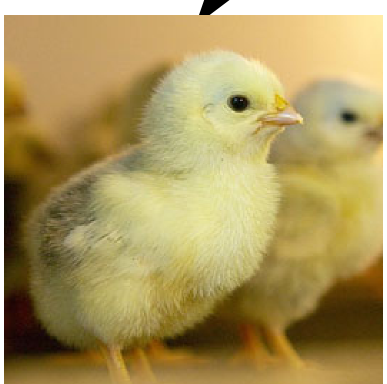
The risk of Blind Acceleration

21 days 37ºC

3 minutes140ºC



Philips Approach for Reliability

- Combination of:
  - Derating rules (individual component basis)
  - Stress testing (many stresses)
    - Acceptable limits are set based on experience
  - Accelerated testing on sub-system level
    - Acceptable limits are set, based on understanding of physics of failure and acceleration factors
    - But there are many failure mechanisms. We have acceleration factors for our top 5 failure modes.
  - Verification testing on system level
  - System Reliability is based on Modeling → Predicted lifetime based on projected field call rates.

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Needs

- Fundamental knowledge and industrial practices to understand the failure mechanisms. Both on component and system level.
- Fast, reliable and cost effective reliability qualification methods / procedures that allow coverage of the total product warranty period
- Acceleration factors (for each failure mechanism) to translate the accelerated test results to actual user conditions
- Multi-location efforts to determine the acceleration factors for each failure mechanism. Cooperate to share best practices and data.

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